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I. Summary

At the moment, the full complement of in situ measurements is being made on amorphous germanium deposited on 4°K substrate using our new cryostat. We have measured the resistivity, optical transmission, reflectance and photoconductivity at temperatures ranging from 4 to 575°K.

The program for studying the optical and electrical properties of amorphous silicon has culminated in several highly relevant discoveries. We have earlier reported that both the optical and electrical properties stabilize at annealing temperatures between 400°C and 600°C above which crystallization then occurs. We find also in this range of annealing temperatures that the log of the low temperature conductivity is proportional to $T^{-\frac{1}{4}}$. This in itself has been seen by others but in addition we find physically reasonable numbers for the parameter of Motts model; namely, the density of states at the Fermi level $N(E_F)$, the fall off parameter of the wave function for localized states near the Fermi level γ, the average hopping energy W and the hopping distance R. This seems to constitute the first complete test of Mott's model.

II. Research Program and Plan

Now that our in situ cryostat, optical system and electronics, is in full operation we wish to investigate the electrical and optical properties of amorphous germanium over the full temperature range from 4°K to 675°K. We plan to look for the effect of in situ annealing in germanium prepared and annealed under ultra high vacuum conditions and see if in situ measurements yield results similar to those obtained under less ideal conditions. We also wish to compare the properties of films prepared at 4°K and annealed to some temperature with that of films directly evaporated onto a substrate

of that temperature. Since most of the previous reports on amorphous germanium have been with samples exposed to ambient gases, we will investigate the changes in transport properties under controlled exposure to various gases.

III. Progress during the Period

1. <u>In Situ Measurements</u>

A number of films of amorphous germanium have been deposited at liquid helium temperature and we have measured in situ the electrical and optical properties. The influence of in situ annealing on these properties has also been investigated. Preliminary results show that the conductivity of a film deposited at liquid helium temperatures is relatively high and is found to increase exponentially with temperature from 50-300°K. Such an annealed film when remeasured from 77-300°K exhibited a smaller conductivity than observed in the as deposited case. The activation energy calculated from these measurements for the annealed film increased with temperature.

The in situ measurements of transmission and reflection in the spectral range of 0.8-2μ show that as deposited films in the studied spectral range have a high absorption coefficient which decreased considerably on annealing to room temperature. The enhanced conductivity and high absorption coefficient of the as deposited films can be intuitively understood on the basis of the presence of a large number of dangling bonds in the as deposited films. On annealing, the number of dangling bonds decreases causing a decrease in conductivity. Also there is an onset of an edge in the absorption coefficient.

In situ photo conductivity measurements are being attempted for as deposited films. So far we have not been able to get a healthy photoconductive signal. Efforts are being made to improve the signal by changing the geometry of the electrodes and increasing the light intensity. Room temperature annealed

films show photoconductivity. The spectral and temperature dependence of photoconductivity of such annealed films is now being studied.

In order to throw light on effect of phonons on the fundamental absorption edge, we have studied the transmission and reflection at different temperatures (4.2, 77 and 300°K). The results of these studies are being analyzed.

2. Electrical and Optical Properties of Amorphous Silicon

The results of this work have been reported at the recent APS solid state meetings in Atlantic City[1] and Washington[2]. In addition we have just completed a letter describing this work.[3] We report on five samples whose starting material ranged in resistivity from ∿10Ω-cm to 5000Ω-cm. All of these showed an anneal stable state for temperatures above 400°C but below the crystallization temperature which is greater than 600°C. In this highly annealed state, both optical and conductivity measurements yield an intrinsic gap of 1.4eV-1.5eV (the gap in crystalline silicon is 1.1eV). If one now investigates the low temperature conductivity of amorphous silicon annealed to this high temperature, it is found that to within experimental error (3%) the conductivity fits a $T^{-\frac{1}{4}}$ law as predicted by Mott.[4] Others have claimed that they have observed Mott's process of hopping conduction at low temperatures. However, previous investigations either had not attempted or had failed to obtain physically reasonable numbers for the parameter of Mott's model. In the one previous case[5] where an attempt to obtain these numbers was made, the numbers were unphysical presumably because the films had been only slightly annealed. The numbers we find are $N(E_F)$ varying between 10^{19} and 10^{23} $cm^{-3}ev^{-1}$, $\gamma^{-1} \sim 1\mathring{A}$, $R(200K) \sim 10\mathring{A}$ and $W(200K) \sim .1eV$. Physically these are reasonable numbers and furthermore satisfy the criterion set by Mott for the validity of this model $\gamma R \gtrsim 8$ and $W >> kT$. In addition, we find

that the optical absorption edge shifts to higher energy with a diminution of the long wavelength tail. This indicates the removal of dangling bonds with anneal.

Finally preliminary work on the photoconductivity of amorphous silicon shows a definite structure below the gap which cannot be attributed to interference peaks as has been suggested elsewhere.[(6)]

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